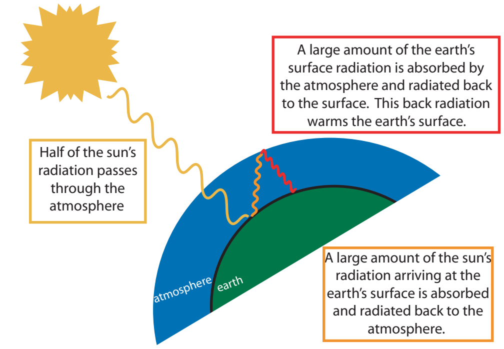
Global Climate Change Primer

What is the greenhouse effect?

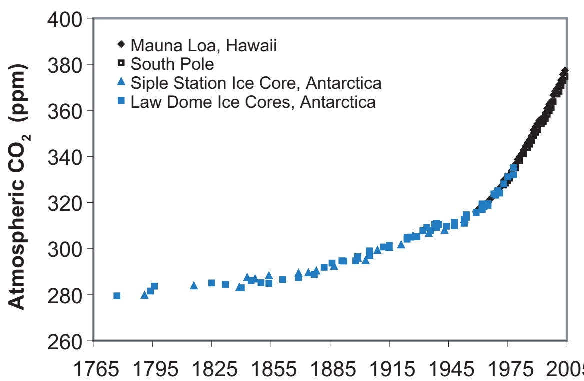
Greenhouse gases in the atmosphere increase the Earth's surface air temperature by absorbing and reemitting radiation from the Earth's surface. Without atmospheric greenhouse gases such as water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2), the globally averaged surface air temperature would be 0 ˚F instead of the currently observed globally averaged surface air temperature of around 59 ˚F.



Sources: Figure based on IPCC Figure 1.2.

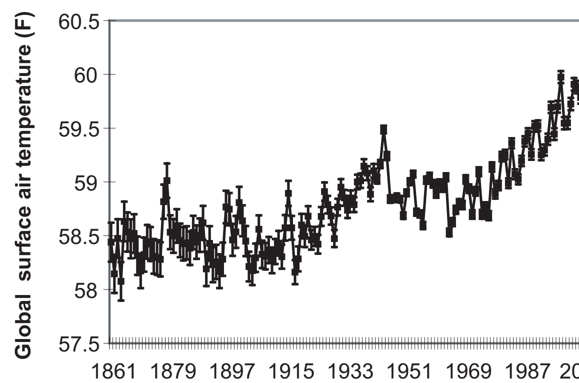
Radiation pathway for the greenhouse effect

RECENT CHANGES RELATED TO THE GREENHOUSE EFFECT



Sources: Keeling and Whorf (2005), Etheridge et al. (1998) and Neftel et al. (1994) http://cdiac.esd.ornl.gov/trends/trends.htm

Atmospheric CO_2 increases over the last 240 years



Sources: Jones et al. (2001), Jones et al. (2003), and Folland et al. (2001)

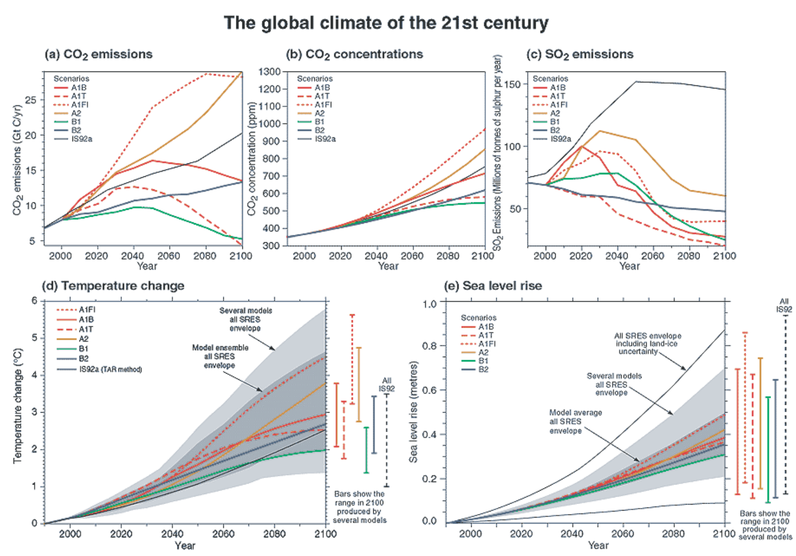
Global surface air temperature increases over the last 144 years

Humans are increasing the concentration of greenhouse gases in our atmosphere. Since the industrial revolution began in 1750, atmospheric CO_2 has increased 34%, atmospheric CH_4 has increased 154%, and atmospheric N_2O has increased 22%. The burning of fossil fuels, forest clearing, and other human activities are largely responsible for these increases. Because of their long lifetimes, these gases will be in our atmosphere for decades to centuries.

In the past century, global surface air temperatures rose 1 ˚F and global average sea level rose 4-8 inches. It is very likely that these global changes are related to increases in greenhouse gases, especially over the last 50 years. Observed global warming has regional variability.

PROJECTIONS OF FUTURE GLOBAL CLIMATE

The 2001 Intergovernmental Panel on Climate Change (IPCC) assessment projects that global surface air temperature could increase by 2.5 to 10.4 ˚F and global sea level could rise 4-35 inches between 1990 and 2100. The amount of projected climate change varies from place to place around the world. Future climate will depend on both natural changes and the response of the climate system to human choices about emissions.



Sources: . Figure 5 from the IPCC 2001 Assessment Working Group I Summary for Policymakers.

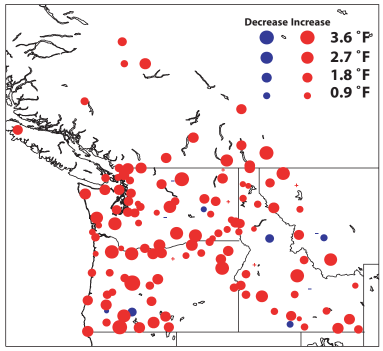
Future climate depends on natural changes and human activities.

Prepared by Jennifer Kay, Joe Casola, Amy Snover, and the Climate Impacts Group (CIG) at the University of Washington for King County's October 27, 2005 Climate Change Conference. This and other conference materials are available at: http://www.cses.washington.edu/cig/outreach/workshops/kc2005.shtml

Regional Climate Change Primer

Observed changes in Pacific Northwest (PNW) climate

Temperature: Observations show that the average surface air temperature in the PNW has increased by ~1.5 ºF over the last century. PNW surface air temperatures increased at virtually every location, with remote areas warming as fast as urban areas.

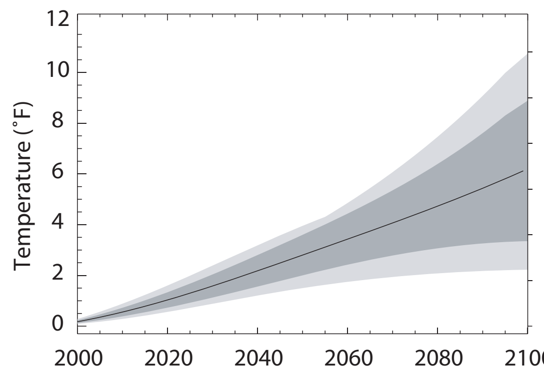


20th century temperature trends

Precipitation: Precipitation changes in the PNW over the last century have been dominated by natural variations between relatively dry and relatively wet periods, rather than by a trend in one direction. For example, a slight increase in winter precipitation occurred from 1916 to 2003, largely resulting from an extensive drought in the 1930s. On the other hand, a strong negative trend in winter precipitation occurred from 1947 to 2003.

Projected 21st century climate changes in PNW climate

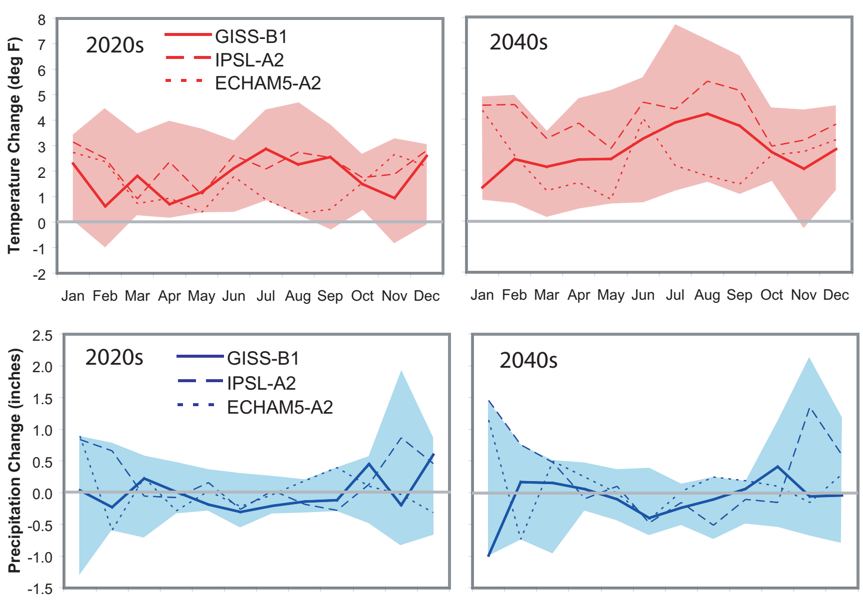
Temperature and precipitation projections derived from 2007 IPCC report (AR4) climate models: Climate models generally project increases in PNW surface air temperatures during all seasons. These projected temperature increases exceed observed 20th century year-to-year variability. Many climate models project small increases in precipitation during the winter, however, projected precipitation changes are smaller than 20th century year-to-year variability. When compared to previous PNW climate change scenarios, AR4 climate model projections show smaller temperature increases and drier 2020s precipitation projections. These differences are primarily due to the consideration of more climate models and an improved method for establishing the baseline to which future changes are compared (All changes reported here are calculated relative to the average climate of the 1970-2000.). Beyond mid-century, climate change projections are less certain because they depend increasingly on greenhouse gas emission choices over the next few decades.



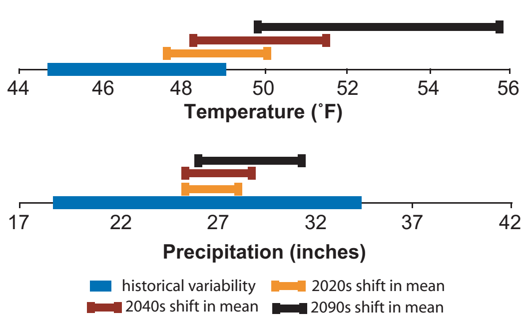
Projected temperature increases

2020s	Temperature (°F)	Precipitation (%)
low	0.7	-4
average	1.9	2
high	3.2	6
2040s	**Temperature (°F)**	**Precipitation (%)**
low	1.4	-4
average	2.9	2
high	4.6	9
2080s	**Temperature (°F)**	**Precipitation (%)**
low	2.9	-2
average	5.6	6
high	8.8	18

Projected changes in annual PNW temperature and precipitation



Projected changes in monthly PNW temperature and precipitation. The lines show changes associated with warm (IPSL-A2), cool (GISS-B1) and middle of the road (ECHAM5-A2) climate change scenarios.



Comparison of observed year-to-year variability and projected shifts in temperature and precipitation from climate models

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Climate Impacts Science Primer: How do scientists project future climates and their impact on resources in Washington State (WA) and the Pacific Northwest (PNW)?

1. Estimate future atmospheric greenhouse gas concentrations and other climate drivers.

Q1 - What do scientists have to know before they can project future climate?

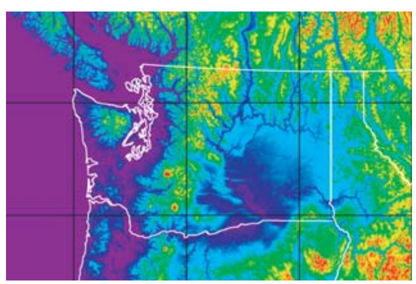
See Climate Impacts Science Questions for answers to Q1-Q9

2. Use global climate models (CMs) to project future climate at a global scale

Q2 - How does a CM work?
Q3 - Why is there so much uncertainty in projected climate changes?
Q4 - Why can I believe climate change projections if it's impossible to forecast weather beyond two weeks?
Q5 - Which CM climate projections are most trusted? Which are less certain?

3. Downscale CM results to project the future climate of WA and the PNW

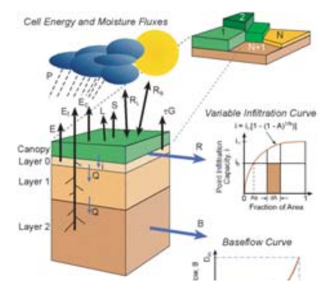
Q6 - What factors control WA and PNW climate?
Q7 - How do scientists "down-scale" CM results to a region like WA?



WA topography with typical GCM grid resolution (~150 miles)

4. Use regional hydrology models to project future snow-pack, streamflow, and soil moisture

Q8 - How do scientists project climate change impacts on the water cycle?



VIC hydrology model

5. Use resource management models or empirical relationships to understand implications for WA and PNW resources

Q9 - How do scientists project impacts on natural resources?

Credit: Mercer Island Parks

Salmon in Lake Washington

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Climate Impacts Science Questions

Q1: What do scientists have to know before they can project future climate?

Before scientists can project future climate, they need to constrain how important climate drivers are likely to change over time. Human socio-economic and political choices influence two important climate drivers: atmospheric greenhouse gas concentrations and atmospheric particle concentrations. The climate of the 21st century will depend on both natural climate drivers and the cumulative impacts of human climate drivers. By making a range of assumptions about future development, global population, and per capita energy consumption, scientists have developed scenarios for future greenhouse gas and particle emissions. These emission scenarios can be put into climate models to project future climate changes (see Q2).

Q2: How does a global Climate Model (CM) work?

A CM is a computer program that solves a series of scientifically established equations to "model" the interactions between major components of the climate system including the atmosphere, the ocean, the land surface, ice sheets, and the biosphere. The relatively coarse resolution of CMs (~150 miles in the horizontal, ~0.6 miles in the vertical, ~½ hour) means some physical processes must be simplified. Most of the uncertainty and differences between CMs comes from the simplification of unresolved processes such as cloud evolution and mixing processes in the atmosphere and ocean. Using a number of CM projections (an "ensemble") identifies a range of possible outcomes, and eliminates biases from a single model. When many independently formulated CMs produce similar projections of future climate, scientists have increased confidence in CM results.

Q3: Why is there so much uncertainty in projected climate changes?

Roughly speaking, uncertainty in climate change projections comes from two sources: uncertainty in future climate drivers (see Q1) and uncertainty in modeling how the climate system works (see Q2). According to IPCC scientists, uncertainty in emissions and in modeling how the climate system works contribute about equally to known uncertainty in future climate change projections. With improved understanding of the climate system, some of the uncertainty in future model projections could be reduced. However, even if scientists had perfect models of the climate system, uncertainty in future socio-economic and political decisions and their influence on human climate drivers will always remain.

Q4: Why can I believe climate change projections if it's impossible to forecast weather beyond two weeks?

Meteorologists model the evolution of individual weather systems and provide weather forecasts at specific times. Climate scientists project the statistics of weather events over longer periods of time (e.g., a season, a decade, or a century). An example of the difference between a weather and a climate forecast follows: A climate projection would state that Januaries in the 2020's will be 3-4 ° F warmer and 4-11% wetter on average than the 1990s while a weather forecast would tell you there is a 70% chance of rain on Friday with a predicted high temperature of 50-55 ° F.

The differences between weather forecasts and climate change projections lead to predictability on different timescales. The sensitivity of weather systems to small changes in initial conditions means that it will never be possible to predict the weather beyond ~2 weeks. The predictability of climate depends on well-understood interactions between the atmosphere and the land surface, oceans, and ice sheets. When climate scientists can identify changes in these interactions (e.g., due to a change in a climate driver such as atmospheric greenhouse gas concentrations), they can project climate changes on long timescales.

Q5: Which CM projections are most trusted? Which are less certain?

Confidence in CM climate projections comes from both comparing CM simulations of past climate to historical climate observations and CM inter-comparison studies. Most CMs can reproduce observed warming trends in the 20th century global surface air temperature when driven by natural climate drivers (e.g., volcanoes, solar radiation) and human-caused increases in greenhouse gases and atmospheric particles. However, agreement between present day climate in CMs and observations decreases for key meteorological variables in the following order: temperature, sea level pressure, and precipitation. Model inter-comparison studies also show that CMs are more consistent in their temperature projections than in their precipitation projections. CMs do not simulate localized climate effects (e.g., the impacts of small-scale topography such as the Cascade Mountains or water bodies such as Puget Sound). CMs also have trouble with the representation of important modes of climate variability such as the El Niño-Southern Oscillation (ENSO).

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Climate Impacts Science Questions Continued

Q6: What factors control Washington state climate?

Latitude, proximity to the large water bodies, and mountain ranges all have large influences on Washington and PNW climate. Season-to-season and decade-to-decade changes in Pacific Ocean temperatures have important controls on Washington and PNW climate variability.

Q7: How do scientists "downscale" CM results to a region like Washington state?

Raw CM output has very coarse resolution (~150 miles) and should not be used directly at a regional scale. To project climate changes in Washington or across the PNW, CM results must be downscaled to a regional level where finer scale influences of topography and water bodies can be resolved. The "delta" method and regional scale atmospheric climate models are two methods used to downscale global climate model results. The "delta" method applies changes from the CM simulations to the historic record of climate. For example, for a 2020 scenario, all the Januaries in the historical record might have their monthly total precipitation multiplied by 1.04 and their monthly average temperature increased by 3.4 °F. This method assumes that only the mean temperature and precipitation, not the variability, change in future climates. High-resolution regional models that are forced by lower-resolution CM output can be run to estimate the fine-scale impacts of climate change. Unlike CMs, regional models include features such as the Cascade Mountain Range and Puget Sound.

Q8: How do scientists project climate change impacts on the water cycle?

After regional scale projections of future climate are obtained (see Q2 and Q7), hydrologic models can be used to project changes in the water cycle. For example, most of the CIG research to date has used the delta downscaling method and the Variable Infiltration Capacity (VIC) hydrology model to estimate the influence of climate change on streamflows. Changes in the water cycle are identified by comparing hydrologic simulations forced by the observed climate and a climate with perturbed temperature and precipitation (see Q7).

Q9: How do scientists project impacts on natural resources?

After identifying potential changes in regional temperature and precipitation (Q7) and the water cycle (Q8), resource management models and empirical methods can be used to understand the impact of climate change on specific resources. For example, the Northwest Power and Conservation Council (NWPCC) recently used altered streamflow scenarios to drive a water management model and estimate the impacts of climate change on hydropower operations. For resources such as forestry and fisheries where quantitative models do not exist or are being developed, empirical methods can be used to estimate the impact of climate change. In other words, we can use observations of how past climate fluctuations have affected the resource to project the impact of future climate changes.

Climate Change Policy Questions
International Summary

Q1 – How is climate change being studied world-wide?

Governments of the world have addressed climate change through the Intergovernmental Program on Climate Change (IPCC). The IPCC was jointly established by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) in 1988 to provide an assessment of the state of scientific understanding of all aspects of climate change, including how human activities might cause climate changes and be influenced by them. The IPCC consists of three working groups: Working Group I assesses the scientific basis for climate change, Working Group II focuses on the impacts of and potential adaptations to climate change, and Working Group III addresses the mitigation (prevention or slowing) of climate change. While the IPCC charter is highly relevant to public policy, the IPCC does not establish or advocate specific actions.

IPCC working groups produce assessment reports by synthesizing up-to-date information from international experts and scientific publications. The first assessment reports (FAR) were published in 1990, the second (SAR) in 1996, and the third (TAR) in 2001. The fourth assessment reports (AR4) should be published in 2007. Professionals from around the world contribute to writing assessment reports through an established, open, and peer-reviewed process. For example, the TAR was co-authored by 400+ scientists and reviewed by 2000+ scientists from around the world. Each IPCC report has a non-technical summary for policymakers, which is approved line-by-line by all governments involved in the IPCC process.

In May 2001, the Bush Administration asked the National Academy of Sciences to organize a group of prominent American climate scientists to assess the current scientific understanding of global climate change and independently evaluate the conclusions of the IPCC TAR. The resulting 2001 NAS report, "Climate Change Science: An Analysis of Some Key Questions", agreed with the IPCC TAR report stating that global warming has occurred in the last 50 years and is likely the result of increases in atmospheric greenhouse gases. The committee also said the full IPCC Working Group I report did an admirable job of reflecting research activities in climate science, and that the current state of knowledge was adequately summarized in the TAR Working Group I technical summary. IPCC assessment reports are available free of charge on the IPCC website (listed below). In addition to producing assessment reports, the IPCC develops climate modeling emission scenarios and creates an open-access archive of all climate model predictions.

Web: http://www.ipcc.ch/

Q2 – What international climate change treaties have been signed? Will they reduce atmospheric greenhouse gas concentrations?

The Framework Convention on Climate Change (FCCC) and the Kyoto Protocol are the two most prominent international climate change agreements. The FCCC is the international treaty guiding intergovernmental efforts to address climate change. It entered into force on 21 March 1994. In total, 189 countries have signed it, including the US on October 15, 1992. Countries ratifying the FCCC officially recognize that the climate system is a shared resource whose stability can be affected by industrial and other emissions of CO_2 and other greenhouse gases. In FCCC Article 2, signatories agreed to "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic influence with the climate system". Signatories meet yearly at Conference of the Parties (COP) meetings to discuss progress, policies, and joint actions.

At the 1997 COP held in Kyoto, Japan, the FCCC signatories adopted a specific strategy for reducing greenhouse gas emissions called the Kyoto Protocol. By ratifying the Kyoto Protocol, industrialized (or Annex I) countries must reduce their anthropogenic greenhouse gas emissions by at least 5% below 1990 levels in the commitment period 2008 -2012. Ratification required adoption by at least 55 countries, including enough Annex I countries to account for at least 55% of the 1990 Annex I emissions. The Protocol entered into force on February 16, 2005 when Russia ratified. Although the US signed the Protocol, it was never ratified by Congress.

Even if the Kyoto Protocol emission reductions are attained, Bolin (1998) estimates atmospheric CO_2 will continue to increase from 353 ppm in 1990 to 382 ppm in 2010. For reference, the current (2005) atmospheric CO_2 is 375 ppm, 34% greater than the pre-industrial (1750) atmospheric CO_2. For stabilization of atmospheric CO_2 at 450 ppm, Bolin and Kheshgi (2001) estimate the global per-capita emissions would have to decrease 45% by the middle of the century. In other words, everyone (including all Annex I countries) would have to have per-capita emissions similar to present-day undeveloped countries. Although the Kyoto Protocol will not prevent future increases in atmospheric greenhouse gases, it does establish an institutional framework for limiting future human greenhouse gas emissions.

Journal Articles:

1) Bolin, B., (1998). The Kyoto Negotiations on Climate Change: A Science Perspective, Science, Vol. 279, Issue 5349, 330-331. 2) Bolin, B., and H. S. Kheshgi, (2001). Inaugural Article: On strategies for reducing greenhouse gas emissions, *Proceedings of the National Academy of Science*, 98: 4850-4854.

Climate Change Policy Questions Continued
National and Regional Summary

Q3 - What US programs and initiatives have addressed climate change science and impacts research?

Started by the Global Change Research Act of 1990, the U.S. Global Change Research Program (USGCRP) has invested almost $20 billion towards their goals: "to increase understanding of the Earth system and to provide a sound scientific basis for national and international decision making on global change issues." More than 60% of the USGCRP program funding is dedicated for development and support of satellite technologies to observe the Earth. In June 2001, George W. Bush established the Climate Change Research Initiative (CCRI) which focuses primarily on areas with significant uncertainty and on obtaining observations in order to reduce those uncertainties. Also in 2001, Bush re-launched the Clinton Administration Climate Change Technology Initiative (CCTI) as the Climate Change Technology Program (CCTP). The CCTP helps develop and deploy technologies that could potentially achieve substantial greenhouse gas emission reductions. In 2003, the Bush Administration merged the USGCRP and CCRI forming the Climate Change Science Program (CCSP) coordinated by a new interagency Climate Change Science Program Office in the National Oceanic and Atmospheric Administration (NOAA).

Web: http://www.climatescience.gov/

Q4 - What has the West Coast done to address climate change research and policy?

Washington, Oregon, and California policymakers and scientists have been very active in climate change research and developing strategies to respond to climate change impacts. In September 2003, the West Coast Governors' Global Warming Initiative was launched by the then Governors of Washington, Oregon, and California. This effort is widely considered one of leading state initiatives on climate change in the United States. The Governors have committed to act individually and regionally to reduce greenhouse gas emissions through strategies that promote long-term economic growth, protect public health and the environment, consider social equity, and expand public awareness. In 2004, the executive committee of the initiative wrote a report documenting recommendations to the Governors for action.

Scientific and policy research centers have been developed in each state to provide information about climate change science and impacts. The University of Washington has hosted the Climate Impacts Group (CIG) since 1995 (see Q5). California has the California Climate Change Center. The University of Oregon is starting a Climate Change Resources Institute to complete social science research and provide technical assistance related to climate change. Across the US-Canada border, British Columbia has started the Pacific Climate Impacts Consortium at the University of Victoria to generate, tailor and communicate relevant climate variability and climate change information to BC stakeholders in the public and private sectors.

In June 2004, the Oregon State University Consensus Statement on climate change was signed by 46 Ph.D. level scientists from the Pacific Northwest. The signatories agree that climate change is underway and that it is having global effects and that it will have significant impacts in the Pacific Northwest.

Web:
West Coast Governor's Global Warming Initiative - http://www.climatechange.ca.gov/westcoast/
California - http://www.climatechange.ca.gov/research/
Oregon - http://cwch.uoregon.edu/programs/GWSCCRC.html
British Columbia - http://www.cics.uvic.ca/

Q5 - What is the Climate Impacts Group (CIG)?

The CIG is a group of interdisciplinary researchers studying the impacts of natural climate variability and global climate change on the Pacific Northwest. They are one of eight Regional Integrated Scientific Assessment (RISA) teams focusing on regional impacts of climate variability and change in the US. CIG researchers have expertise in climate dynamics, hydrology, forestry, aquatic ecosystems, coastal systems, human health, societal dimensions, and integrated assessment. Funding for the CIG comes from NOAA's Office of Global Programs with additional resources provided by the University of Washington. CIG personnel completed much of the research included in the report you are now reading.

Web:
CIG - http://www.cses.washington.edu/cig/
NOAA RISA - http://www.risa.ogp.noaa.gov/